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TABLE OF CONTENTS

PRODUCTION OF A SPATIAL FILTER WITH HIGH EFFICIENCY AND BROAD DYNAMICAL RANGE BY USING COMPOSITE HOLOGRAM AND BLEACHING TECHNIQUE

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(Received 9 April 1979)

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A method is described which produces a spatial filter with high efficiency and broad dynamic range by using a composite hologram and bleaching technique. The method was used in processing defocussed, blurred images and good results have been abtained.

I. INTRODUCTION

When making a deblurred spatial filter [1] a filter with a dynamic range as broad as possible is required in order to recover images with the best fidelity and high resolution. For example, in the processing of seriously defocussed blurred images, a filter with a linear dynamic range of more than 100:1 is normally required. Silver plate recording material with high resolution can only be achieved normally up to 10:1. Obviously, it is difficult to achieve more than 100:1 using silver-plate as the recording material without using some special methods. Many people have done much work in this field to broaden the dynamic range of the spatial filter. On the basis of a spatial filter with high efficiency and broad dynamical range using the holographic method suggested by S. L. Ragnarsson [2] we use the composite hologram technique to broaden further the dynamical range of the filter. This method in principle can broaden the dynamic range to any value required.

II. THEORY

The spatial filter made by S. I. Ragnarsson's method is in substance a weak reference bleaching pure-phase-hologram. The

total phase delay of the emulsion after bleaching consists of the sum of the relief-image produced by the expansion of the emulsion and the reflected images produced by the change in the refraction index of the emulsion. In order to eliminate the effect of the relief-image, the filter must be placed in a liquid-gate.

The arrangement used in recording the filter is shown in Fig. 1. A pinhole is placed at the front focal plane P_1 of the lens L_1, at a distance d from the optical axis. A transparent plate with an amplitude transmissivity of h(x,y) is also placed at the plane P_1, with its center on the optical axis. When illuminated with a coherent plane wave, the distribution of

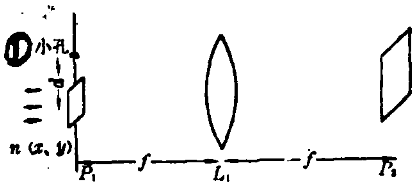


Fig. 1 Recording arrangement of filter
Key: 1--pin-hole

the optical field at the back focal plane is given by

$$a_2(u, v) = Ae^{-j\pi \frac{d}{\lambda f} u} + |H(u, v)| e^{-j\theta(u,v)} \quad (1)$$

where H(u,v) is the Fourier transform of the pulse response function h(x,y) (depending on blurring factor), u,v are the spatial frequencies, θ(u, v) is the phase of H(u, v). The exposure of the film corresponding to such an amplitude distribution can be expressed as:

$$\varepsilon(u, v, t) = E(u, v, t) \times \left\{1 + M(u, v) \cos\left[\pi \frac{d}{\lambda f} u - \theta(u, v)\right]\right\} \quad (2)$$

where

$$E(u, v, t) = t(A^2 + |H(u, v)|^2) \quad (3)$$

$$M(u, v) = 2A|H(u, v)|/A^2 + |H(u, v)|^2 \quad (4)$$

t is the exposure time. Under the condition of $A^2 \ll |H(u, v)|^2$ the first order diffracted amplitude distribution of the filter

after the bleaching process is given by [2, 3]

$$T(u, \nu) = \frac{A}{H(u, \nu)}\left[\frac{1}{A^2/|H(u,\nu)|^2+1}\right]\tau(E)e^{j\phi(E)} \qquad (5)$$

where the first facter, proportional to $H(u, \nu)^{-1}$, is the right spatial filter we require. By selecting the proper value of A^2 in the second factor

$$\frac{A}{A^2/|H(u, \nu)|^2+1} = \frac{1}{A}\frac{|H(u, \nu)|^2A^2}{|H(u, \nu)|^2+A^2} \qquad (6)$$

and multiplying by the first factor, the optimum filter function A^2 can be obtained. $\tau(E)$ is the slope of the function curve between the phase delay of emulsion and the logarithm of the exposure, and it describes the error in amplitude. If it has a constant value of τ_0, over the whole exposure range, then the filter has no error in amplitude. The fourth factor indicates a phase error. If the phase error can be controlled so

$$\phi[tH^2(0, 0)] - \phi[tA^2] \leqslant \frac{\pi}{4} \qquad (7)$$

then the amplitude transmissivity of the filter may be obtained as

$$T(u, \nu) = \frac{\tau_0}{AH(u, \nu)}\frac{|H(u, \nu)|^2A^2}{|H(u,\nu)|^2+A^2} \qquad (8)$$

According to Eq. (3), the maximum exposure is $tH^2(0,0)$ and the minumum exposure tA^2. If the minimum value of the linear region of the function curve between phase delay Ø(E) and log E_a, and the maximum E_b, then

$$\frac{H^2(0, 0)}{A^2} \leqslant E_b/E_a \qquad (9)$$

is required. Both the developing liquid with low and high dynamic range and the bleaching technique to broaden the dynamical range can be used, but the dynamical range we obtained is still limited by the limitations of Eq. (7) and Eq. (9). If we divide $|H(u, \nu)|$ into two parts, $|H(u, \nu)| > B$ and $|H(u, \nu)| < B$ where B is a constant, and take holographic recording in the

region of $|H(u,\nu)| \geqslant B$ by using reference intensity $A_1^2=B^2$, and $tA_1^2=E_a$, $tH^2(0,0)\leqslant E_b$ then the filter function $T(u,\nu)\propto\frac{1}{H(u,\nu)}$ can be obtained in this region. In the region of $|H(u,\nu)|<B$ the film can only get the minimum exposure E_a at this time. Thus $\frac{B^2}{A_2^2}<\frac{E_b}{E_a}$, $tA_2^2=E_a$ can also be obtained by using another reference intensity A_2^2, and making holographic recording with the assumption $T(u,\nu)\propto\frac{1}{H(u,\nu)}$. If we define the dynamic range obtained by the single hologram as R_1 , and the dynamic range of the resultant hologram as R_2, then

$$R_2=\frac{H^2(0,0)}{A^2}$$

$$=\frac{E_b}{E_a\frac{E_a}{E_b}}=R_1^2 \qquad (10)$$

The procedure is as follows: First, make a recording by using reference intensity A_1^2 ; second, keep the recorded film static, and insert a membrance with an assumed transmissivity of zero at $|H(u,\nu)|^2\gg A_1^2$ and one at $|H(u,\nu)|^2<A_1^2$ in the optical path, and process after a second recording by using the reference intensity A_2^2. The exposure at the second exposure region is given by

$$\varepsilon_2(u,\nu,t) = E_1\left[1+M_1\cos\left(\pi\frac{d}{\lambda f}u+\theta(u,\nu)\right)\right] + E_2\left[1+M_2\cos\left(\pi\frac{d}{\lambda f}u+\theta(u,\nu)\right)\right] \qquad (11)$$

where

$$E_1=t_1(A_1^2+|H(u,\nu)|^2) \qquad (3)$$

$$M_1=2A_1|H(u,\nu)|/A_1^2+|H(u,\nu)|^2 \qquad (4)$$

$$E_2=t_2(A_2^2+|H(u,\nu)|^2) \qquad (12)$$

$$M_2=2A_2|H(u,\nu)|/A_2^2+|H(u,\nu)|^2 \qquad (13)$$

t_1 and t_2 are the first and second exposure times respectively. Within this region,

$$A_1^2\gg|H(u,\nu)|^2\gg A_2^2 \qquad (14)$$

Let

$$t_1A_1^2=t_2A_2^2 \qquad (15)$$

We then have

$$\varepsilon_2(u,\nu,t) \approx E_2\left[1+M_2\cos\left(\pi\frac{d}{\lambda f}u+\theta(u,\nu)\right)\right] \qquad (16)$$

$$T_2(u,\nu) = \frac{A}{H(u,\nu)}\left[\frac{1}{A^2/|H(u,\nu)|^2+1}\right] \times r(E)e^{j\phi(E)} \qquad (17)$$

As long as these two exposures are kept within the linear region of curve $\phi(E)$ - $\log(E)$ and Eq. (7) is valid, we then have

$$T(u, \nu) \propto \frac{1}{H(u, \nu)} \qquad (18)$$

for a larger range. By dividing the dynamic range

$$R_n = R_1^n \qquad (19)$$

can be obtained, where n is dividing number.

III. EXPERIMENTAL RESULTS

1. Character of the Emulsion

In order to determine the optimum exposure time and expected dynamic range, the phase characteristic of the emulsion must be found first. It can be calculated by changing different exposures and recording a holographic grating with constant modularity, and measuring the relationship between the first order diffracted efficiency of the holographic grating and the exposure after processing the film, and according to reference [3]

$$\tau(E) = \frac{2\sqrt{\eta(E)}}{M} \qquad (20)$$

and

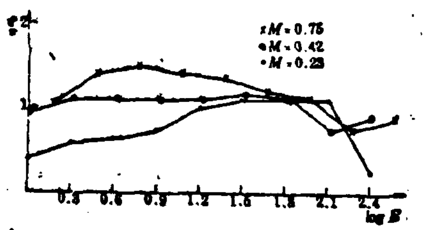
$$\tau(E) = d\phi(E)/d\log(E) \qquad (21)$$

where $\eta(E)$ is the first order diffracted efficiency, M is modularity. Because of the changing of H(u,v), modularity M takes on any value over the range of 0~1. The statistical explanation requires a group of curves with different modularity. From the curves it can be seen that the diffracted efficiency is independent of exposure over a certain range. In this experiment the processing method of dry plate Kodak 649F is selected; see table 1. The sinusoidal grating and the changing of modularity are obtained by using the coherence of direct splitting beams of a He-Ne laser with about 2.5mw of power and changing the splitting beam ratio. Three modularities of 0.75, 0.42, 0.23 are obtained by the experiment. Exposure time runs from 1/15 seconds to 256 seconds. The

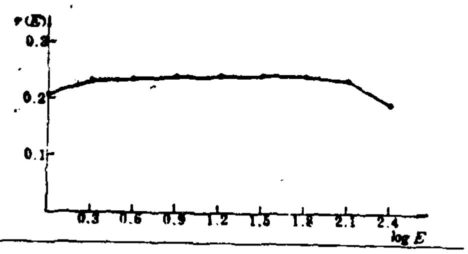
results are shown in Fig. 2. The dynamic range we obtained is about 80.

Table I Processing of film

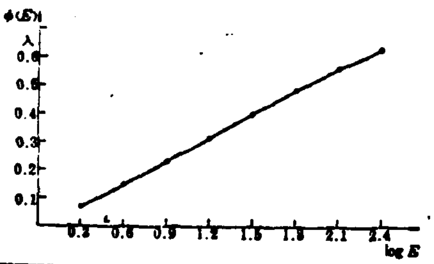
Fixing emulsion	Rinsing	Developing	Stop developing	Fixing	Rinsing	Bleaching	Rinsing	Cleaning	Rinsing
SH-5		Pota 22 C 1/min.	2% ethanoic solution	F-5		5% copper bromide solution			
3 min.	30 sec.	5 min.	30 sec.	5 min.	5 min.	7 min.	5 min.	5 min.	10 min.



(a) Function-curve between diffracted efficiency of emulsion and exposure.



(b) Function-curve of $r(E)$-log(E) (obtained by averaging three curves of (a)).



(c) $\phi(E)$-log (E) Curve (obtained by numeric integral of (b)).

Fig. 2

2. Input Plate

In order to facilitate the determination of the pulse response function, the sample with 36 radiating strips is selected, and the script of three Chinese words 消模糊 (deblurred) is also selected. A 35mm camera with relative aperture of 2.8 and f=50mm is used, its focused object distance purposely changed from 0.65m to 0.90m. The spatial frequency of the first phase reversal of the radiating strips after developing is 2.39 lines/mm. The diameter of blurring disk obtained is 0.5mm.

The positive and negative films are used to make the input plate. The negative film is recorded by Agfa 10E75 under the above conditions. Developer 1:25 D-165 solution is used for eleven and one half minutes. The positive film is Kodak 649F, and the developer is 1:10 D-165 solution for eight minutes. These two developing processes occur at 20°C, with mixing 82 times per minute. The multiplication of the two r's obtained consecutively equals approximately 2.

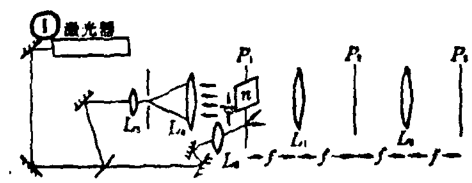
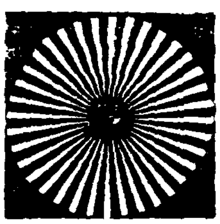
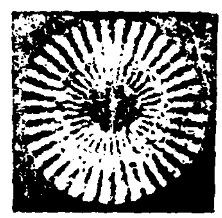


Fig. 3 Arrangement of experimental devices.
Key: 1-Laser



(a) In-focus image of radiating strips.

(b) Defocussed image of radiating strips.



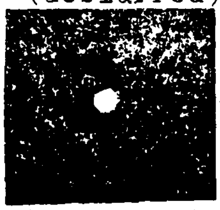
(C) Recovering image of radiating strips

(d) In-focus image of [illegible] (deblurred)

(e) Defocus image of [illegible] (deblurred)

(f) Recovering image of [illegible] (deblurred)

(g) Blur circle.



(h) Recovering point

Figure 4

3. Making of Filter

The arrangement of the optical path of this experiment is shown in Fig. 3. The procedure of the experiment is as follows: First, place a 649F film in the plane P_2, with its emulsion surface backward. With reference light blocked, record $|H(u,v)|^2$ and develop with solution D-19, and keep the transmissivity in the region of $|H(u,v)|^2 > A_1^2$ at zero and the transmissivity in the region of $|H(u,v)|^2 < A_1^2$ at one. Second, put the membrane made during the first step back to its original place and position a film 649F closely near its back surface, and make the first holographic record with reference plane wave of intensity A_2^2. Third, take down the membrane made at the first step and make the second holographic record with a plane wave of reference intensity A_1^2. Fourth, process the film obtained according to table 1.

We have $H^2(0,0)/A_1^2 \approx 80$, $A_1^2/A_2^2 \approx 12$, $t_1 \approx 10t_2$, $R \approx 900:1$.

4. Experimental Result

The filter is replaced strictly in the plane P_1 and the image to be processed is placed in the plane P_2. With the reference light blocked, the result is recorded in the plane P_3, as shown in Fig. 4.

From the experimental result it can be seen that this method is easy and feasible, but the result is not yet ideal due to the limitations of our experimental conditions.

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[1] G. W. Stroke, R. G. Zech; *Phys. Lett.*, 1967, **25A**, 69.
[2] S. I. Ragnarsson; *Phys. Scripta*, 1970, **2**, 145-153.
[3] AD-785904.

LETTERS

INAUGURAL MEETING OF THE OPTICAL SOCIETY OF CHINA HELD IN BEIJING

CHANG Ai-chun, ZHAO Run-qiao, LIU Zhen-tang

The inaugural meeting of the Optical Society of China was held in Dec. 10-15, 1979. The 314 representatives of the organizations engaged in optical science research, production and teaching from 24 provinces, cities, and autonomous regions attended the meeting. Vice-premier FAN Yi was present and made an important speech. On behalf of the State Council, Mr. Fang first warmly congratulated the establishment of the Optical Society of China. He pointed out that the Optical Society of China should be established never as a bureaucratic apparatus, but instead a real scientists' home run by themselves. He ardently expected the representatives and all opticists to work hard together and make optics contribute towards the realization of the four modernizations. Mr. Yan Ji-ci, vice president of the China Association for Science and Technology, deputy dean of the Chinese Academy of Science, delivered an opening address. He reviewed the developing history of research of Chinese optical science, and pointed out that the purpose of establishing the Optical Society of China was to organize and unite the optical scientists and technicians through various activities of the optical society. He also hoped that they could emancipate the mind and work harder to devote themselves to realization of the four modernizations. Mr. WANG Daheng, a famous opticist, made a report on "Some Progress in the Field of Optical Science and Technology in China". He set forth the major successes achieved by the optical science research and production for thirty years since the founding of People's Republic of

China and the glorious task of Chinese optical scientists and technicians.

Mr. Shu-Zhow, vice president of the China Association for Science and Technology, Mr. SUN Jun-ren, deputy minister of Ministry of the Fourth Machine Building, Mr. JIU Zhen-dong, leading cadre of the Ministry of the Eighth Machine Building, director general of th Optical Society of Beijing, Mr. Song Ding, vice chairman of Science and Technology Committee of Beijing as well as leading cardres in charge of science research and production from ministries, committees and science and technology bureaus, and the representatives of other societies concerned also attended the meeting.

The meeting received congratulatory telegrams and letters from Prof. Lehmann, Chairman of International Optical Society, Prof. Osiyo Kijisi, Tokyo University of Japan, on behalf of National Optical Committee of Japan, Mr. Saitou, Tokyo University of Japan, on behalf of department of Applied Physics and Optics, Prof. Siyunda Ubi, Hokkaido University of Japan, and Spectra Physics Co. of U.S.

The meeting collected 429 academic theses recommended by organizations concerned throughout the country. The academic activities of the meeting took place from 11 to 14 December. The optical scientists and technicians read 142 papers at separate sessions, and made extensive academic exchanges in the fields of Fundamental Optics, Engineering Optics, Laser, Infrared Technology and Optical Materials. Prof. Andrew Marshall, chairman of European Optical Society, director of Paris Theoretical and applied Optical Research Institute of France, and Dr. Wang Zhen-ting of Ford Motor Co., were invited and presented academic reports at the meeting.

Engineering Optics was developed early in China. There were many opticists and technicians in this field, and 71 theses about that field were read at the meeting. Some of them reached a higher technical level, for example, design of optical systems using

automated design programs in general. Design of a Fourier Transform lens with high precision yielded more ideal results. There were also considerable successes in the design of optical instruments, optical transfer functions as well as film coating and graduating technology etc. It is an occasion of celebration that some progress of scientific research work in the field of information processing of applied optics was made. Information processing is a new subject in the development of the applied optics science in the world today.

Laser science is one of eight important sciences and technologies to be developed with emphasis in China. It was given more attention by the government and developed rapidly. At the laser session, 34 papers were read and the work experiences about laser devices were exchanged. It represented the development of laser devices in China towards the far infrared and ultraviolet. The types of laser devices were increased and the technical level of equipment was raised constantly. These successes brought about new conditions for developing of laser applications.

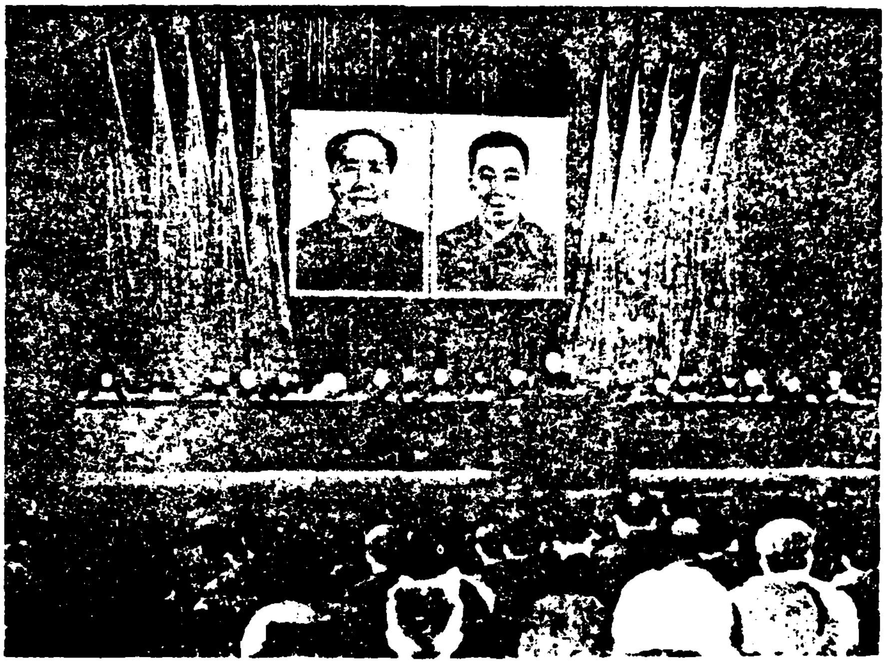
Fundamental Optics was a weaker link of optics developed in China. But from this meeting it could be seen that the situation was improving and good achievements were obtained in some aspects. In the fields of infrared technique and optical materials, besides reports and exchanges, visits to science research and production facilities were still being organized in Beijing. Numbering over 50,000 in all, over 240 kinds of papers and technical data sent by organizations were circulated at the meeting.

Because the optical scientists and technicians had paid attention to combining theory with practice and science research with production, many academic papers had higher theoretical level and larger practical value. Through this academic exchange activity, various academic thoughts were stimulated, and many valuable suggestions were proposed for work on optical science and technology in the future. It is believed that these suggestions would have a good

influence upon the attending delegates and the mass of optical scientists and technicians.

After earnest discussion and correction by the delegates, the constitution of the Optical Society of China was passed. A veteran in the field of optics, Mr. YAN Ji-ci, deputy dean of the Chinese Academy of Sciences, was elected honorary director general of the Optical Society of China. 143 directors of the first board of society and 43 directors of the standing board were chosen by secret ballot. Mr. WANG Da-heng won the vote for the director general of the board, Mr. GONG Zu-tong and 11 other members were elected the deputy-directors and Comrade SU Wei the secretary general. Seven special committees on Fundamental Optics, Engineering Optics, Lasers, Infrared and Optical-electric Devices, Optical Materials, Optical Information and Popular Optical Science, and a working committee were established. The plan of academic activities in 1980 was proposed by the committees. The meeting also decided to establish a special committee on Photonology. In order to discuss the achievements in optical science research, the society still decided to publish "ACTA OPTICA SINICA" and form a editorial board. The administrative body of the society was set up.

The meeting came to a successful close on Dec. 15, 1979. The delegates made up their minds to unite and strengthen the exchanges with the optical scientists and technicians throughout the country, and work hard together to march towards the advanced world levels of optical science and technology under the leadership of the Chinese Communist Party.



LETTERS

LASER THERMAL CONDUCTIVITY TESTER CONTROLLED BY ELECTRONIC COMPUTER DEVELOPED BY DIVISION OF SCIENCE AND TECHNOLOGY, SHANGHAI SILICATE MATERIALS INSTITUTE, ACADEMIA SINICA

The Laser thermal conductivity tester (LTCT) was developed by Shanghai Silicate Materials Institute (SSMI), the Chinese Academy of Sciences, in cooperation with Shanghai Laser Technology Institute, Shenyang Metal Materials Institute, the Chinese Academy of Sciences and Shanghai Iron & Steel Institute in 1973. By making great efforts for many years an advanced electronic computer technique was applied to the measurement of thermal physics of materials by SSMI. Recently, LTCT controlled by electronic computer was developed and passed the test.

LTCT is a new type of equipment for measurement of the thermal conductivity coefficient using the laser technique. The thermal conductivity coefficient is one of the important thermal physical parameters of materials, especially as an essential item of key data for astronautical materials. The accuracy, speed, automation level and function of measurement of LTCT are considerably improved by using electronic computer control. Practical measurement indicates that the principal specifications of the instrument have approached the advanced international level. Measurement errors are reduced from ±8~9% to ± 4~6%. Speed of measurement is raised about 100 times. Repetition rate of measurement is also enhanced greatly, and many diverse tasks such as making picture and picking-up points as well as accidental errors introduced by these operations are avoided. The whole measurement process except the measurement of temperature is entirely automated.

Besides the measurement of thermal conductivity coefficient of burnt-eroded materials on the nose cone of Returning-Earth-Satellites, the thermal conductivity coefficients of ceramics and coatings, metallics and alloys, glass, single crystals and ferroelectrics as well as composite materials such as phenolics-polyester and carbon-quartz also can be measured. At the present, the measurable

range of temperature is about 300~2100°C. If further improvement can be made, the measurement range of temperature can be still extended at both ends. The delegates attending the appraisal meeting considered it a good multiple-technique precision instrument, which can be used in measurement and science research. They all suggested expanding its application range.

NOTES

PRELIMINARY APPLICATIONS OF LASERS IN CHINESE VETERINARY SCIENCE

WANG Shao-wei

PEDAGOGIC RESEARCH GROUP OF CHINESE VETERINARIANS, THE VETERINARY UNIVERSITY OF THE CHINESE PEOPLE'S LIBERATION ARMY

Lasers have been applied extensively to medical science from fundamental medicine to clinical science and physical diagnosis of many treatments, and remarkable successes have been achieved. But there are not enough reports about the application of lasers in clinical veterinary science.

Our school uses a type Spring city-3 of He-Ne laser with an output of 5mw made by Changchun South-Ridge Laser Electric Factory as a laser needle. Some clinical treatments are given. Clinical experience confirmed that laser needle acupuncture treatment is also indeed effective in Chinese Veterinary science. For concrete curative effects see the table below.

Through clinical practice, we consider that the laser needle acupuncture treatment can enhance the disease-resistance of the spleen and kidney, and strengthen bones and muscles. Illumination by a laser can heat and open up passages (through which vital energy circulates) and regulate the functions of the spleen and stomach to recover one's appetite. The laser can also give full play to its function of a heater and optical source, dredge main and collateral channels (along which the acupuncture points are distributed) and mediate the function of vital energy and the state of the blood to invigorate the circulation of the blood and disperse the old blood, and regulate the flow of vital energy and assuage the pain. Therefore, the laser needle applied to clinical Chinese veterinary science has a certain value.

CASE	ANIMAL -TIME	ACUPUNCTURE POINT	TIMES OF LASER NEEDLE TREATMENT	NO. OF CURED ANIMALS	NO. IN STABLE COND.	NO. TURNING BETTER	NO. FAILING TO TREAT
Gastric disorder causing nausea	4	Main acupoint: Pishu, Baihui Sub acupoint: Bashan, Xieqi	8~17	4			
Eating plant slowly by illness	8	Main acupoint: Paishu Sub acupoint: Guanyuanshu, Housanli	1~10	8			
Limp	5	Qiangfeng, Bashan, Baihui, Xieqi	8~17	4		2	
Godema and abdominal distension	2	Affected part	2~11	1	1		
Sequelae of sprain	1	Baihui, Yaohou, Bashan	10			1	
Bad bedsores	1	Baihui, Pishu, Affected part	16			1	
Paralysis caused by encephalitis of young	1	Tianmen, Baihui, Qiangfeng, Hips	8				1